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Technical Report

NEAR Gamma Ray Spectrometer Characterization and Repair

Contract NAS5-32486 Final Report - Year 3

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Contents

1.0 SCOPE

The report covers the work completed in the third year of the NASA NAS5-32486 PIDDP contract. The principle activities during this period were (1) the characterization of the NEAR 2 Gamma Ray Spectrometer using a neutron generator to generate complex gamma ray spectra and a large Ge Detector to identify all the major peaks in the spectra, (2) the evaluation and repair of the Engineering Model Unit of the Gamma Ray Spectrometer for the NEAR mission, (3) the investigation of polycapillary x-ray optics for x-ray detection and (4) technology transfer from NASA to forensic science.

2.0 CHARACTERIZATION OF THE NEAR GAMMA RAY SPECTROMETER

2.1 Setup

The NEAR Gamma-Ray spectrometer characterization studies were carried out at the Schlumberger-Doll Research (SDR) neutron generator laboratory. Participants in the characterization effort included Joel Groves, (Schlumberger/EMR Photoelectric), Wolfgang Zeigler and Charlie Archer, (Schlumberger-Doll Research), Jeff Schweitzer, (Consultant), Richard Starr and Larry Evans, (Goddard Space Flight Center), Johannes Bruckner (Minz).

Schlumberger-Doll Research's radiation safety procedure for operation of neutron generators required at least one Schlumberger radiation worker to be present at all times when the neutron generator was on. Teams of SDR/EMR and NASA representatives were formed to cover the full 24 period so that data could be collected continuously.

The facility used to characterize the detector was constructed earlier under the PIDDP program to characterize the response of gamma-ray and x-ray detectors for NASA planetary missions. Previously, the Schlumberger neutron generator facility was used to characterize the responses of Ge detectors that had undergone radiation damage and were of the type originally planned to be used on the Russian MARS96 mission. In addition, the facility has a formation that simulates the surface of Venus, which can be used to generate spectra with the degree of spectral complexity that would be commonly encountered on a planetary body.

The facility consists of a pulsed 14 MeV neutron generator mounted along one side of wooden box containing silica and nickel bar stock. Gamma rays are produced by inelastic neutron scattering and thermal neutron capture by the silicon, oxygen and nickel in the wooden box and by the hydrogen, iron and other elements present in the surrounding walls. The NEAR Detector and a Ge detector are mounted along the side of the box opposite the neutron generator. The high resolution gamma ray spectrum from the Ge detector is used as an aid in the spectral deconvolution and characterization of the NEAR spectra. Additional information on the neutron generator facility for the characterization of gamma-ray detectors can be found in the first year final report for

NASA Contract NAS5-32486 entitiled "First Year PIDDP Report on Gamma-Ray and - X-Ray Spectroscopy".

For the characterization of the NEAR 2 Gamma-Ray Spectrometer, the neutron generator was operated to give a relatively low output of approximately $1x10^7$ neutrons/second (HV = 57 kV, I_B = 73 μA). Initially, a Ge detector from Goddard Space Flight Center with an efficiency of 30% was used. About halfway through the data acquisition, this detector was replaced with the SDR's 96% efficient Ge detector that had been used for all previous characterizations using the neutron generator facility. The SDR Ge detector detector had been at Ortec for repair. The Ortec measured energy resolution and efficiency on return was 2.06 keV and 91.9%, respectively.

The spectral processing of the Ge detector measurements was performed with standard laboratory electronics and the spectra were acquired on a laboratory PC. The data acquisition system for the NEAR 2 Gamma-Ray Detector used the Ground Support Electronics and the Engineering Version of the onboard flight electronics.

2.2 Data collection

The NEAR Detector and associated electronics were unpacked and installed in the SDR neutron generator facility on April 10. An initial problem in getting the system to operate was overcome by reloading the EPROM in the electronics that duplicates the onboard system. On April 11, initial energy calibrations with sources were performed. The spectra in the BGO detector were checked to ensure that the windows for the 511 keV and 1022 keV peaks were properly positioned. The neutron generator was turned on to determine proper settings for operation with an acceptable dead time for the BGO.

The delayed activation count rates created in the crystals, especially the BGO detector, were studied to optimize the shielding of the NEAR detector. After optimization, the final shielding consisted of paraffin on the outside, with lead bricks on the horizontal sides of the NEAR detector, underneath it and at the back. Inside this configuration was B_4C loaded rubber to absorb low energy neutrons. Inside the rubber was a thin lead sheet, except in the front and back of the detectors, to attenuate the 478 keV gamma rays produced by the (n,α) reaction in the boron. The effect of the shielding was to reduce the background count rate in the BGO detector by about a factor of 5 and in the NaI(Tl) detector by about a factor of 2.

Following these efforts, a background run was started on the evening of April 11 which continued to the morning of April 14. On the morning of April 14, the characterization runs were started and the Ge detector spectra were accumulated. Late in the day, the data from the background runs were analyzed and a problem was observed in the anti-coincidence spectrum. The manifestation of the problem was that at low energies the anti-coincidence spectrum looked correct. But at some intermediate energy (in this case,

about 1 MeV), the anti-coincidence spectrum appeared to be losing counts compared to what was expected. And at a slightly higher energy (in this case, about 2.2 MeV) all channels contained essentially zero counts in the anti-coincidence spectrum. This behavior was then duplicated using ^{22}Na and ^{232}Th sources. After looking at details of the energy calibration, it was decided that the BGO threshold setting of "3" might be too low. By raising the BGO threshold setting to "6" it appeared that the problems disappeared for the calibration sources. Runs were started at these new settings and it appeared that the character of the anti-coincidence spectrum was improved. It should be noted that the data in the other spectra appeared normal.

On the morning of April 15, the data from the overnight run were examined. While the problem at the low energies, e.g., at the hydrogen lines, appeared to have disappeared, there still appeared to be a problem at higher energies around 4-5 MeV and above. A number of tests were made to try to understand the source of this problem. Two possible hypotheses were considered: (1) a light leak between crystals and (2) electronic crosstalk from the NaI channel to the BGO channel. The opinion of the NEAR Detector design engineer at EMR was that light leakage between crystals was highly unlikely (An estimate of the light leak was that if about 0.1% of the NaI light leaked into the BGO crystal, the observed behavior could be explained).

Since investigation of the possibility of a light leak between the NaI and the BGO parts of the NEAR Detector would require that the NEAR Detector be disassembled, efforts were focused on identifying any electronic problems. The cables were changes and shortened between the preamplifiers and the amplifiers. There was no change in the response. By raising the BGO threshold to "10," data were obtained that appeared to cover almost the full energy range in the anti-coincidence spectrum. The negative consequence of this action was that some gamma-ray events at energies lower than the photo peak would now appear in the anti-coincidence spectrum. This can be seen clearly in the region of the hydrogen peak where events are present in the anti-coincidence spectrum down to the Compton edge. It was decided that this was a reasonable compromise to obtain the most useful data. A long data accumulation run was started late on April 15 with a BGO gross count rate of about 6 kHz which corresponded to a 68% BGO live time. The output of the neutron generator was stable to within about 2% thus maintaining a constant count rate in the detectors and minimizing gain shifts.

Early in the morning of April 16, a failure in the neutron generator grid power supply resulted in about one hour of down time until the problem could be repaired. The neutron generator then continued operating satisfactorily. About noon, the data accumulated during the first 16 hours was reviewed. It appeared that the anti-coincidence spectrum seemed to have the expected response. At that time it was decided that the run should continue.

The large volume Ge detector of Schlumberger was returned from Ortec about 10 AM on April 16 and was cooled down for about 8 hours. The specifications for the Ortec detector when new were an energy resolution of 2.09 keV and an efficiency of 91.9% at

the 1333 keV peak of ^{60}Co. The detector was checked for energy resolution and found to be acceptable (about 2.2 keV at the 1333 keV peak of ^{60}Co). The GSFC Ge detector was replaced by the Schlumberger Ge detector at about 9 PM. The B_4C shielding that had been around the GSFC detector was placed around the Schlumberger detector.

Upon turning on the neutron generator, the dead time in the Schlumberger detector was found to be too high because of the high detection efficiency. Therefore, a 0.25 inch layer of lead was wrapped around the sides of the detector to reduce the count rate from multiply scattered gamma rays. This reduced the dead time to about 15% which was considered acceptable. From this time onward, the Ge data were obtained with the Schlumberger detector. Energy resolution was better than that obtained with the GSFC detector (e.g., 6.49 keV for the Schlumberger detector versus 8.77 keV for the GSFC detector at the 6.129 MeV line from ^{16}O). All other data acquisition continued normally and there was no down time, as the neutron generator operation continued without any interruption.

Data acquisition continued on April 17 and 18 with no unusual occurrences. There was no down time from equipment failure. Since the SDR Ge detector had limited holding time (about 24 hours under normal conditions), it was removed for a couple of hours additional cooling in the middle of the afternoon to allow the fill time to be after the completion of the acquisition run with the neutron generator. Approximately 100 hours of Ge and NEAR data were acquired.

2.3 Results

Sample Ge and NEAR spectra are shown in the following figures. Analysis of the results will be reported later.

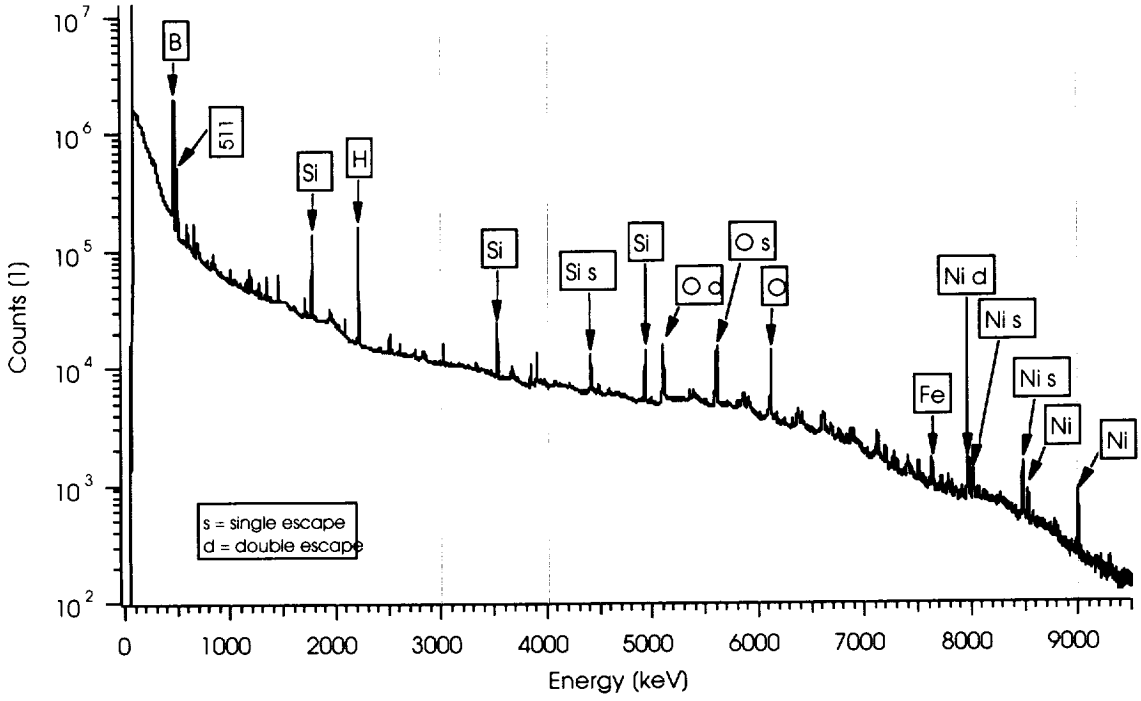

Figure 2: Sample Ge spectra taken with the Schlumberger detector.

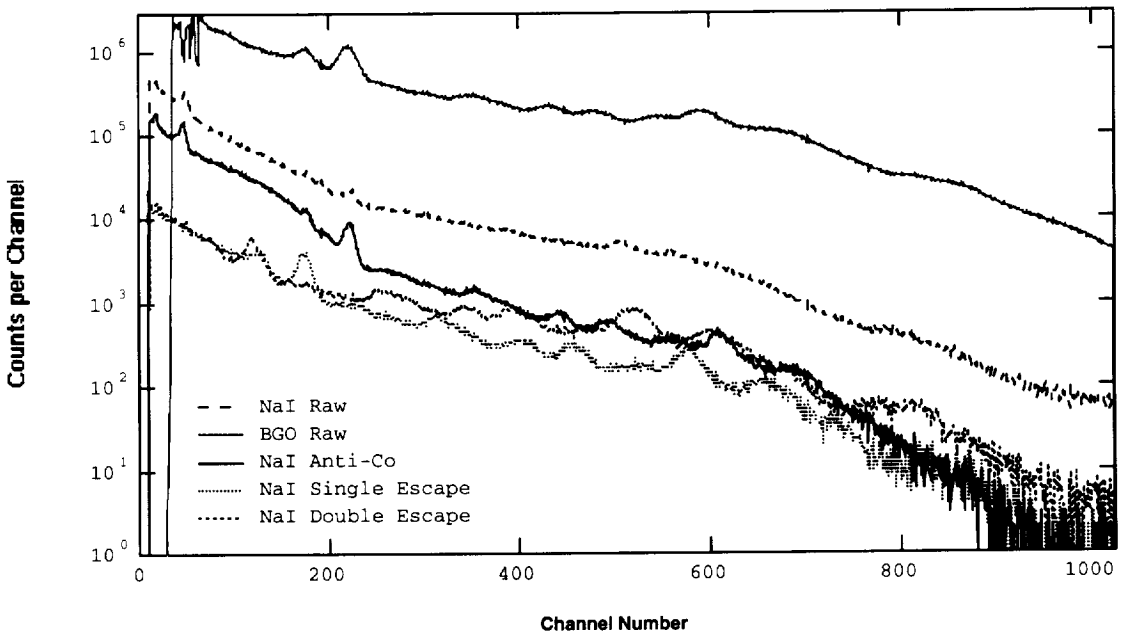

Figure 3: Sample spectra taken with the NEAR Detector.

3.0 NEAR ENGINEERING UNIT EVALUATION AND REPAIR

3.1 Introduction

The EMU detector was received on February 12th , 1998. Three electronic files were forwarded to EMR in advance: EMU spectra with gate on the BGO at 100 keV, EMU spectra with gate on BGO at 360 keV, and Spare Detector spectra with gate on BGO at 82 keV. The anti-coincidence spectrum of the NaI(Tl), expected to have no effect on the photopeaks but a measurable rejection on the Compton scattering portions, showed the expected behavior for the Spare Detector. Similar results were found for the EMU detector if the discriminator level on the BGO signal was set to 360 keV, but the photopeak of the 2.614 MeV gamma ray was completely rejected (see Figure 3.1) if the discriminator on the BGO was lowered to 100 keV. Figure 3.2 shows the spectra with the higher discriminator level, for comparison.

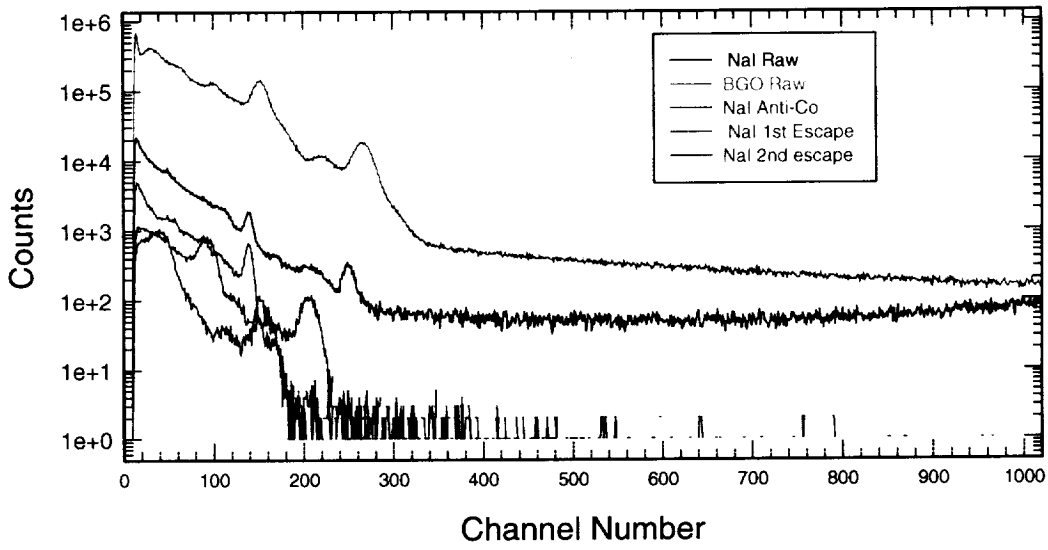

Figure 3.1 Unusual rejection of the thorium photopeak (channel 245) in the NaI(Tl) anti-coincidence spectrum (blue curve) as compared to the normal NaI(Tl) spectrum (red curve). BGO discrimination level is at 100 keV. Collection time = 215,694 seconds

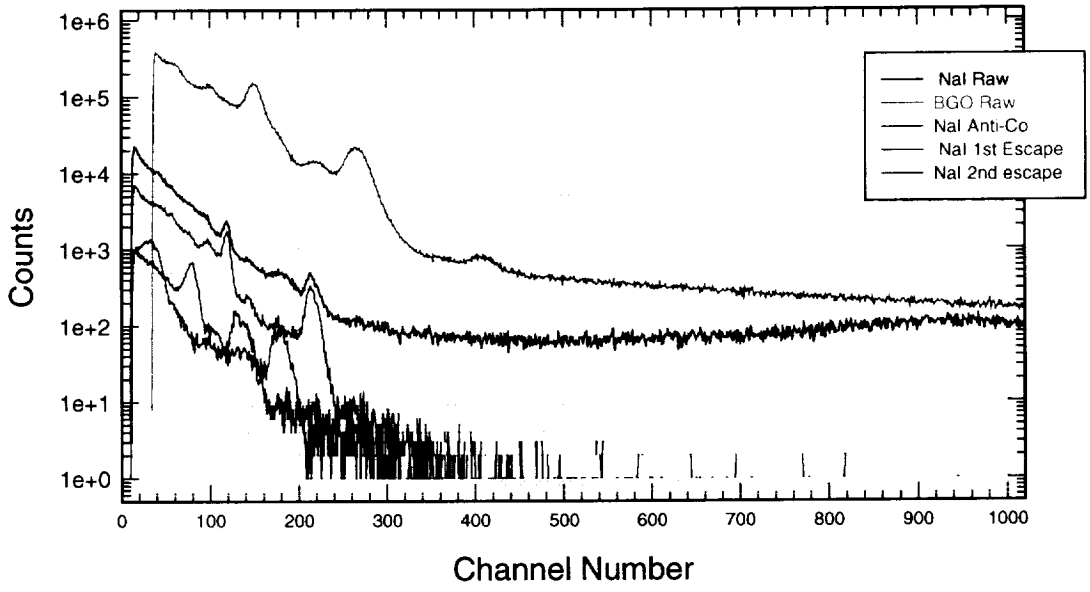

Figure 3.2 No rejection of the thorium photopeak (channel 220) in the NaI(Tl) anti-coincidence spectrum when the BGO discrimination level is at 360 keV. Collection time = 230,400 seconds

These results were interpreted as being consistent with a small leakage of the light generated in the NaI(Tl) crystal by a gamma ray into the BGO crystal. The higher the energy of the gamma ray the more light will go into the BGO, and at certain energies that light will be over the discriminator threshold on the BGO detector. Another possibility was discussed with Sam Floyd (the NASA representative), as being induced by some instrumentation electrical ground problem.

3.2 Diagnostic Activities

The EMU detector was energized at EMR with standard laboratory electronics. The raw data indicated that the detector had resolution performance of the NaI(Tl) and of the BGO detector roughly the same as when it was first delivered to JHU-APL in May 1994.

For the rejection problem a coincidence setup was assembled. The block diagram of the setup can be seen in Figure 3.3.

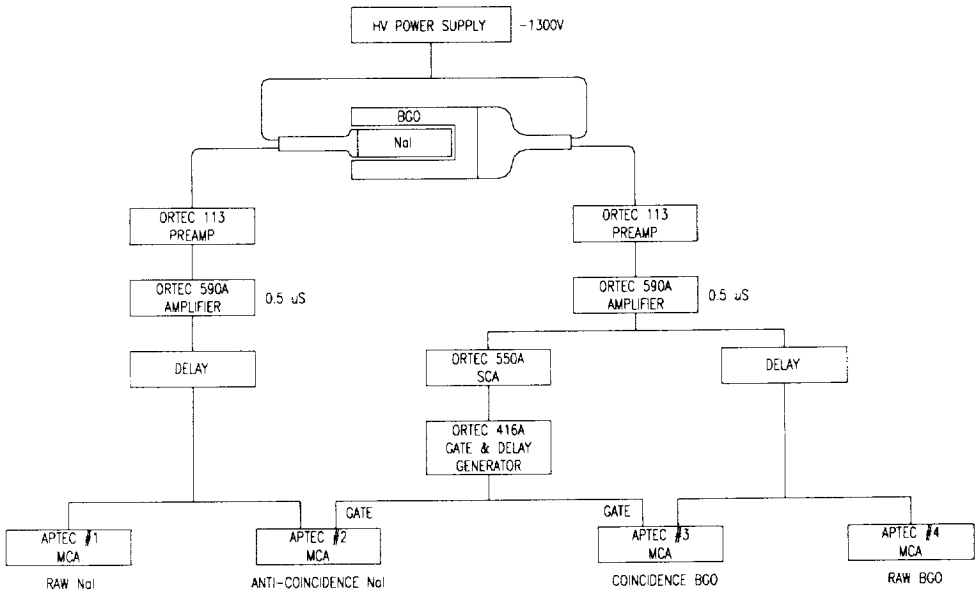

Figure 3.3 Block diagram of the experimental setup used throughout the repair work. The delay lines were set to 4.25 μs, close to their maximum of 5 μs, to synchronize the gate signal with the spectroscopic signal. As the gate is generated on the tail of the signal, the shaping of the signal influenced the data acquisition. To use the system we were forced to use 0.5 μs shaping on both the NaI(Tl) and the BGO detectors, less than the optimum of 1 μs at room temperature. This choice affected the ultimate resolution values on the two detectors.

The setup allowed to record simultaneously 4 spectra:

a. Raw NaI(Tl) spectrum

b. NaI(Tl) spectrum in anti-coincidence with the BGO spectrum

c. Raw BGO spectrum

d. BGO spectrum in coincidence with the gate generated by the BGO signal passing through a discriminator.

This arrangement provided both the BGO spectrum and the level of the discriminator level, so that one can see directly the spectrum-calibrated discriminator level.

Spectra similar to the ones shown in Figure 3.1 and 3.2 were collected. The radioactive source was made of a large number of camping lantern mantles (containing natural thorium in form of an oxide) wrapped on a stainless cylinder. This source was placed at the end of the NaI(Tl) PMT cap, for reproducible positioning. Raw count rates in the two detectors were: 27.5 cps in the NaI(Tl) detector and 960 cps in the BGO detector. Figure 3.4 shows a calibration spectrum of the Gated BGO detector (it should be identical with the Raw BGO spectrum, but small differences between the Aptec Multi-Channel Analyzers were observed).

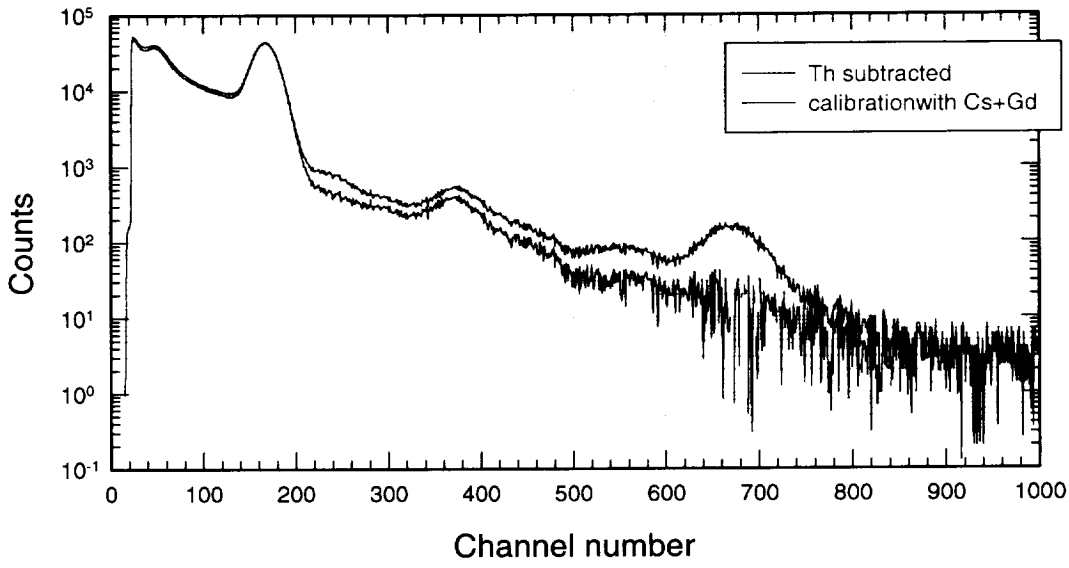

Figure 3.4 Energy calibration of the gated BGO spectrum, using ^{153}Gd (100 keV), ^{137}Cs (662 keV). Accumulation time was 1800 seconds, count rate was 2775 cps. Also visible (green curve) are the thorium lines at 2614 keV and its first escape peak, and the ^{40}K (1460 keV) line. If one subtracts a normalized thorium spectrum one emphasizes the 1460 keV line with little interference from the second escape of the 2614 thorium peak. The calibration was performed by a linear fit to the 662, 1460 and 2614 keV lines: E_γ=3.844keV*channel+25.4 keV. The 100 keV line of Gd is chopped by the discriminator.

The calibration spectrum was taken using the thorium source (2,614 keV) described above, a 10 μCi Cs source (662 keV) and a 10 μCi Gd source (100 keV). In order to obtain an intermediate energy point, the thorium spectrum was subtracted (in a

normalized fashion), and this emphasized the ^{40}K line (1,460 keV) coming from the test building structure (walls, concrete floor).

Figure 3.5 shows the four spectra taken with a discrimination level of 217 keV, using only the thorium source: this result is similar to the one obtained by NASA (see Figure 3.2).

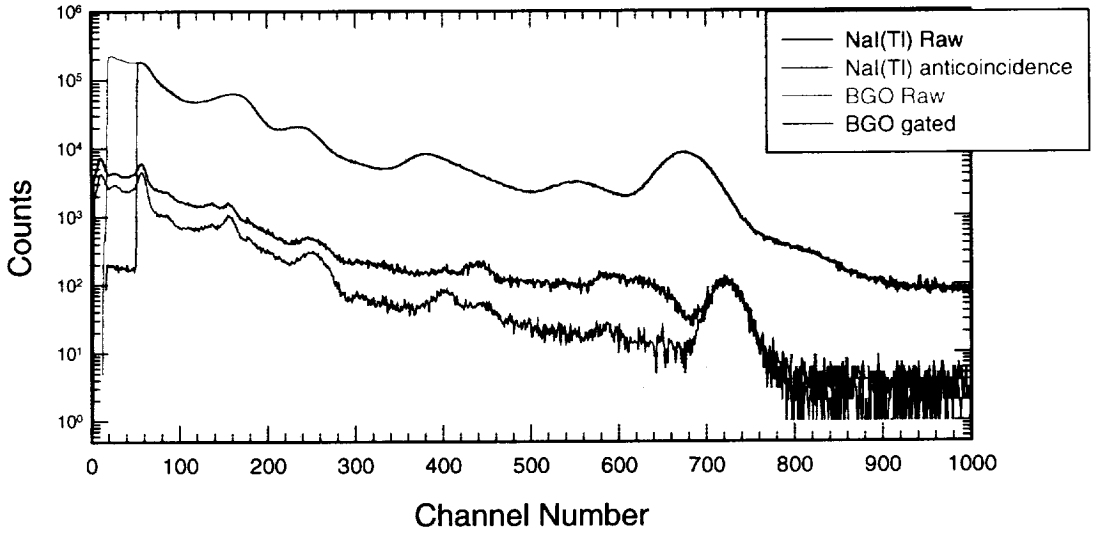

Figure 3.5 Spectra taken with a thorium source for a live time of 21,600 seconds (6 hours). No rejection is visible at the 2614 keV level (channel 722 in the NaI(Tl) spectra). The discrimination level was 217 keV (channel 50 in the BGO spectrum). Note that the analog discriminator provided a rejection of only 3 orders of magnitude, but this was enough to identify the problem.

Another experiment was made with a different discriminator level. The discrimination level was lowered until the electronic noise started getting into the spectra. If one rises this level slightly, to eliminate the electronic noise, one gets the spectra shown in Figure 3.6. The estimated discrimination level was 100 keV. The rejection of the photopeak is very visible. Straight line background subtraction provided a rejection ratio of 9:1. This is an approximate number, as the straight line background would over-estimate the background in the raw NaI(Tl) spectrum, given the fact that the Compton edge is not completely separated from the photopeak.

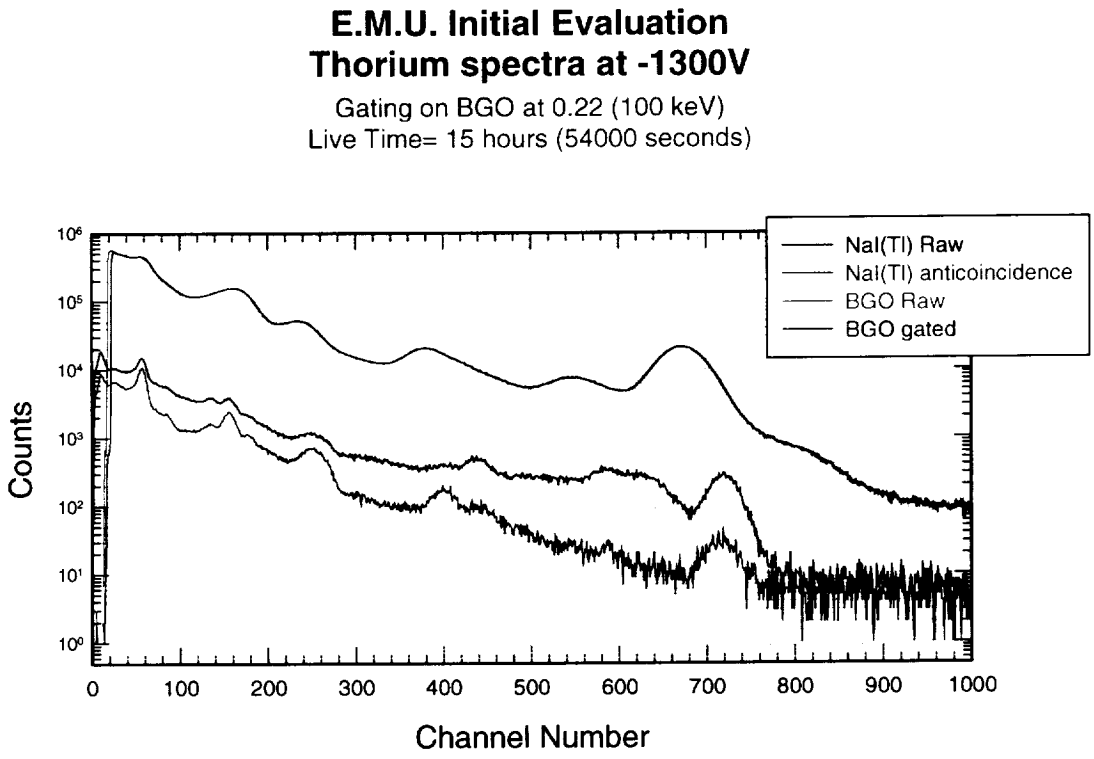

Figure 3.6 Spectra taken with a thorium source for a live time of 54,000 seconds (15 hours). The rejection at the 2614 keV line is very clear (ratio of raw photopeak to gated photopeak areas is 9:1) . Discrimination level on the BGO gating signal was at 100 keV.

The spectra in Figure 3.6 confirmed the measurements provided by NASA. It also allowed us to calibrate our system and quantify the rejection rate. The rejection was not as complete at the 2614 keV line as that obtained in the NASA experiments (see Figure 3.2), but this may be attributable to differences in the electronic setups.

Although the above experiments confirmed the effects seen at NASA, a certain amount of work was done to see if different grounding schemes of the detector and, separately, the instrumentation can produce similar effects. One of the computer monitors in the test area generates a fairly large amount of electronic noise, and it was used as an additional "ground-problem-producing" device. All efforts to reproduce the above-described photopeak rejection were unsuccessful by this method.

3.3 Corrective Action

The detector was carefully disassembled and the parts were inspected. A critical inspection area was the faceplate of the small PMT, coupled to the NaI(Tl) crystal. This area has been covered with PTFE reflectorizing tape at assembly. This tape had a dual role: to improve the light transmission from the NaI(Tl) crystal to its PMT, and to provide the light reflector to the BGO well at this area. This tape was partially removed from the intended optical region, indicating a possible path for light from the NaI(Tl) crystal to the BGO crystal. The cause for the partial removal of the tape was a mechanical interference produced by tight tolerances and a machining defect of the EMU BGO crystal. This defect (asymmetric machining by 0.020") may have caused the wrinkling of the reflector tape when the detector was first assembled, as it created an interference between the BGO well and the hole in the closing aluminum plate of the housing. The unusual rejection observed in the operation of the detector could definitely be caused by this lack of optical separation between the two crystals.

At this stage it was also confirmed that the reflectorizing applied to the surface of the NaI(Tl) crystal package, intended to help the light collection in the BGO, was wrinkled and did not properly cover the aluminum sides of the NaI(Tl) crystal package. It was also confirmed that the tolerances on some of the detector housing parts were too tight (these parts were already corrected on the Flight and Spare units), especially in view of the fact that the EMU BGO crystal had a machining defect. No other defects were encountered.

The repair of the detector started in the critical area of the 1.25" PMT faceplate. The NaI(Tl) crystal package was separated from its PMT and all surfaces were cleaned. The crystal package was then re-connected to the PMT faceplate by an optical coupling that was cast in place. Performance of the detector was then checked with the standard data acquisition setup and it was found similar to the initial performance. A reflector teflon tape was applied to the faceplate area. A thin aluminum foil was wrapped over this reflector tape, insuring that no light can pass through this area. Another wrap of reflectorizing tape was wrapped over the aluminum foil, to provide the required reflector for the BGO crystal when the NaI(Tl) assembly will be slid into the well.

A new reflector tape was wrapped around the aluminum housing of the NaI(Tl) crystal, in a pattern different from the original one. The tape used was thinner than the original tape that was found wrinkled (0.002" vs. 0.010", respectively). Several practice exercises were performed with this assembly to see if it can be inserted into the BGO well without disturbing the reflector tape. The best reflector wrapping pattern was then finally applied, including a glued reflector button on the end of the NaI(Tl) crystal package.

Several additional steps were taken in order to generally improve the EMU assembly:

- the closing aluminum plate (part 549-2963, Rev.-) was re-machined, bringing the inside diameter from 1.270" to the 1.290" used in the later units (see 549-2963,

Rev.C). This removed the mechanical interference that may have caused the reflector partial removal and wrinkling.

- the pressure plate (part 549-2961, Rev.-) under this closing plate was also modified, changing its inside diameter from 1.270" to 1.310" (all tolerances are ±0.005"), making sure that it does not scratch the applied reflector.

- aluminum foil (light duty, thickness less than 0.001") was put over the BGO crystal reflector wedge (part 549-2960) shoulder, to light-seal the area where the closing plate is attached (this foil takes the place of the O-ring 549-3090-2 that was used in the later units - no space for an O-ring was available, as the closing plate was not upgraded with the O-ring groove).

- aluminum foil (light duty, thickness less than 0.001") was put over the potted 3" PMT shoulder, to light-seal the other end of the detector (this foil takes the place of the O-ring 549-3090-1 that was used in the later units). A small amount of aluminum foil was also put around the back of the 3" PMT, where the wires come out from the housing, although no light leak was detected in this area.

- an O-ring was fabricated from Viton material of 0.032" thickness, and it was placed at assembly on the potted 1.25" PMT. This is similar to the O-ring part 549-3090-3 used in the Flight and Spare units, but of a smaller diameter material, as the small PMT housing (549-2964) was not upgraded with the chamfer employed in the later units.

- After final assembly, a black material made of the potting compound (Sylgard 184) mixed with a black pigment was applied to the wire opening of the 1.25" diameter PMT housing. This material replaces the Epoxy Adhesive Scotchweld #2216, not available at the present time.

For reference, the assembly drawing of the Flight Unit is reproduced in Figure 3.7, with the mentioned parts highlighted in red.

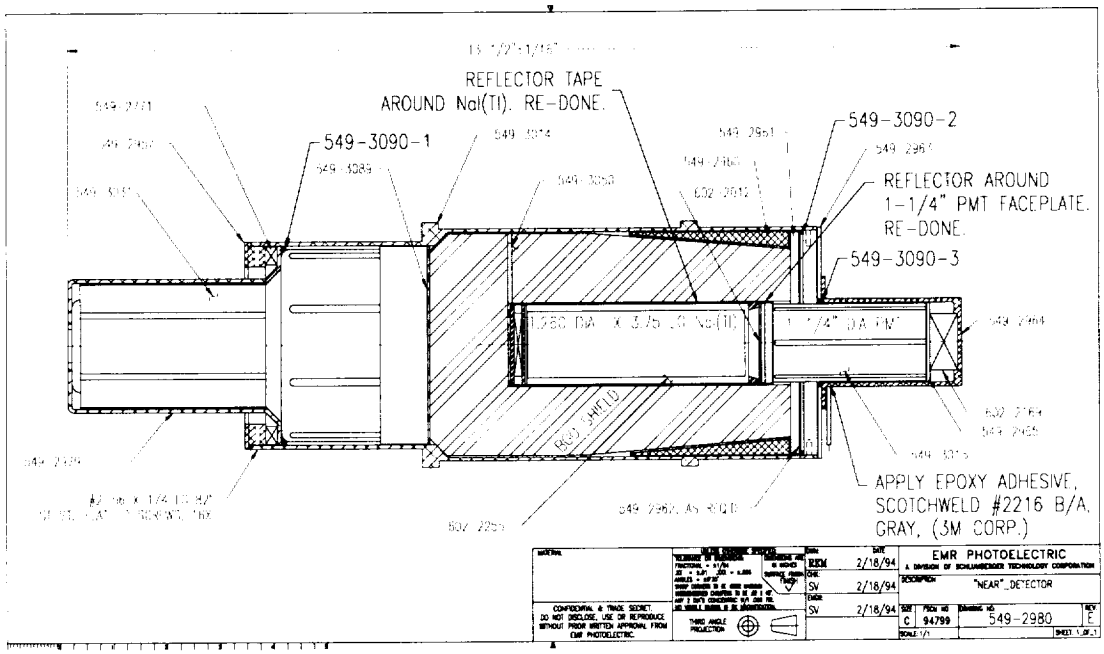

Figure 3.7 Assembly drawing of the N.E.A.R. Flight Unit. The areas highlighted in red were worked on in the upgrade of the EMU unit (see text above) This upgrade insured the light tightness of the EMU unit.

The effectiveness of the upgrade actions was checked with the detector operating at its nominal voltage (-1300V). A black cloth that was used to block light to the detector during tests was gradually removed from the different areas of the detector. No effects of light penetrating to the detector were observed. The final step was to use of a flashlight to illuminate several potential light leak areas. The results of this probing were negative. Most subsequent tests (including those with the high energy source in a different test facility) were done with the detector not covered by anything. With electronic adjustments, the noise level that was observed in the initial spectra was brought down to less than 50 keV in both the NaI(Tl) detector (the 41 keV line of the 153Gd source was clearly visible) and the BGO detector. This confirmed the success of sealing the external light leaks.

3.4 Coincidence Tests with Repaired Detector

Nuclear tests similar to those described in Chapter 3.2 were performed after the re-assembly of the detector. A quick test with the discriminator level at several positions between 217 keV (the value at which a rejection factor of 9 was measured before, see Figure 3.6) and about 40 keV showed no visible differences. A statistically significant set of spectra was collected for 54,000 seconds with the thorium source. The result can be seen in Figure 3.8:

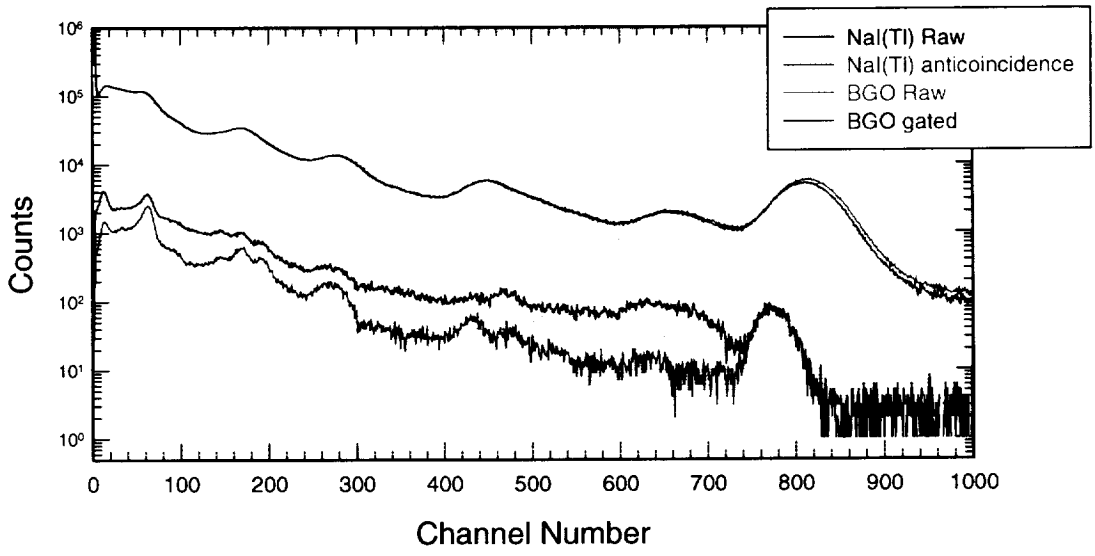

Figure 3.8 Spectra accumulated (live time = 18,000 seconds) with a thorium source after the repair of the detector. The discrimination level on the BGO detector was less than 60 keV. No rejection in the photopeak at 2,614 keV (Channel 772 in the NaI(Tl) spectra) is detected.

The rejection effect before the repair was gamma-energy dependent: the higher the energy of the gamma ray the more pronounced the rejection. This can be understood if one considers that a (constant) fraction of the light generated by the gamma ray is leaked into the BGO crystal. Above a certain energy the light fraction leaked into the BGO exceeds the discriminator threshold, and the NaI(Tl) signal is rejected by the anti-coincidence circuit.

Taking this into account, and also the intended use of the detector - for gamma rays up to 10 MeV - an attempt was made to use a source with a higher energy. Such a source exists at EMR but its use is regulated by the the Safety Procedures of EMR that prevent its removal from a high-level radiation facility. The source is a non-exempt AmBe neutron

source. A careful effort to assess the radiation hazard in a prolonged use was initiated, and a procedure to safely use the source for gamma ray tests was developed.

The tests with this source were then performed in the high-level radiation facility, after moving the test setup to this building. The energy calibration on the detector was changed to about 6 keV/channel, to accommodate the 4,443 keV gamma-ray of ^{12}C in the 1024 channel spectra. The result of a 50,000 second measurement is shown in Figure 3.9.

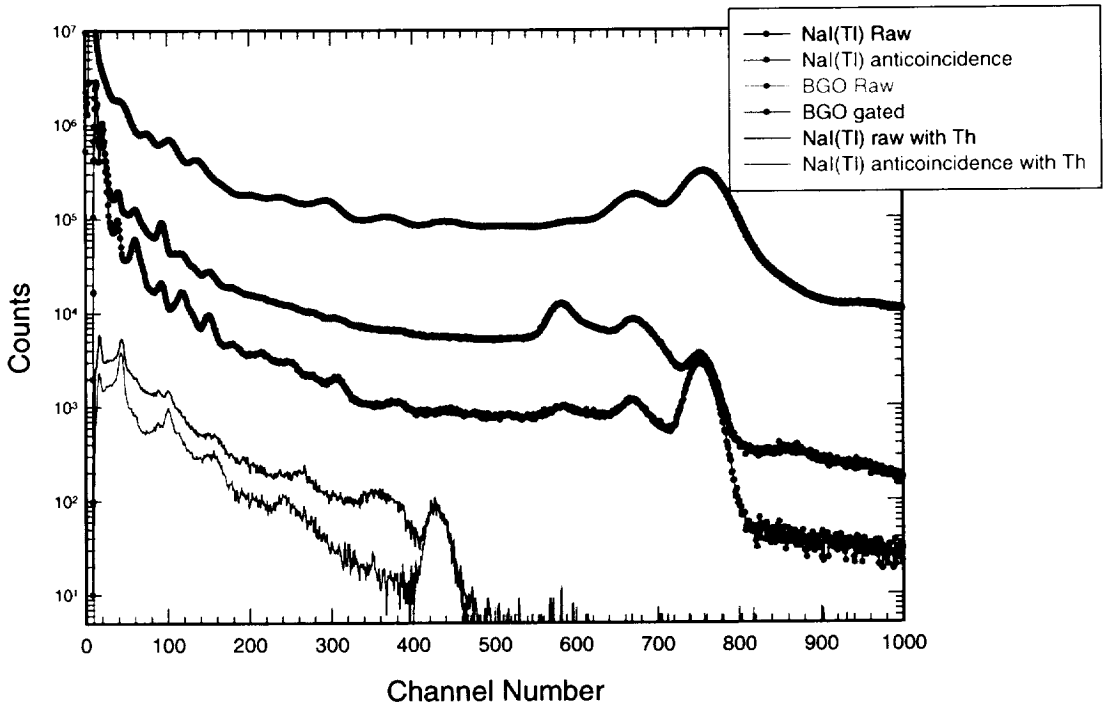

Figure 3.9 Spectra taken with the non-exempt AmBe source (live time = 50,000 seconds). The count rate in the BGO detector was 20,000 cps, while the count rate in the NaI(Tl) detector was 670 cps. No rejection is seen in the 4,443 keV photopeak (channel 750 in the NaI(Tl) spectra), while the Compton and escape peak rejection is almost an order of magnitude (second escape peak rejection ratio is even higher). The discriminator level on the BGO detector was below 60 keV.. A 10,000 second calibration run taken with the thorium source was added. No rejection of the 2,614 keV photopeak (channel 427 in the NaI(Tl) spectra) is present.

This last test showed that the repair was successful. Additional spectra that were used for calibration were collected using the thorium source alone (10,000 seconds) and then the Gd, Cs and Th sources together. This sequence was necessary given the count-rate-dependent gain on the NaI(Tl) detector.

3.5 Conclusions

The N.E.A.R. Engineering Model Unit of the Gamma Spectrometer was returned to EMR due to a malfunction. The malfunction, described as a rejection in the NaI(Tl) spectra, of elevated energy gamma rays when the BGO shield discriminator was quite low, was confirmed at EMR. The corrective action taken was to improve the light-containment in the NaI(Tl) part of the detector. Tests showed that the corrective action was successful, up to a gamma ray energy of 4.44 MeV.

Additional measures taken were directed towards upgrading some of the parts of the detector to correct ambient light leaks. The tests showed that these actions were successful too, and the detector can be used without the protective tape that was employed before.

It is recommended that the detector, when returned to NASA, to be exercised in conditions similar to those in which the photopeak rejection effects were discovered. It would be also important to confirm that the photopeak rejection does not happen with the NASA electronics at higher gamma ray energies.

Shorter data acquisition times can be accomplished at NASA and elsewhere using thorium spectra generated with the radioactive mantles that EMR employs. These are exempt sources, easily available, inexpensive, and easily disposable. The strength of the calibration source can be controlled by the number of units used.

4.0 POLYCAPILLARY X-RAY OPTICS

Polycapillary optics for focusing x-rays of energy up to 100 keV have emerged in the last few years as a powerful tool for controlling, focusing and filtering x-rays. Such an optics contains thousands of individual channels with typically 10 μm diameter open channels. The channels are thin walled, so that the fiber cross section is 65% open area. The x-rays are transported through the capillaries by total external reflection. Polycapillary optics have the advantage of being able to collect x-rays over a large angular spread and area and bring the entire incident flux to a sharp focus.

For planetary measurements the use of polycapillary optics have two distinctive applications. The first is in improving the solid angle collection, permitting the use of much smaller, lighter and better energy resolution x-ray detectors. This reduction in weight is partially compensated by the weight of the optics. However, the use of small detectors might allow a reduction in the number of x-ray detectors, where multiple filtered detectors must now be used to separate the x-rays from some of the important light rock-forming elements, such as sodium, magnesium and aluminum.

The second application is with the use of an x-ray generator. Under such conditions polycapillary optics can increase the intensity of the beam produced by the generator by focusing beam produced over a wide angular flux into a sharp focus that can be used efficiently for detection. This is particularly important for x-ray diffraction measurements in addition to x-ray fluorescence measurements. This improved efficiency in use of produced beam can significantly reduce the power requirements for an x-ray generator and may also reduce its weight. Naturally, if a generator is used, both types of polycapillary optics can be used simultaneously. It is worth noting that this is not the only possible application for capillary optics. They can also be used to focus a wider field of view onto a pixillated detector such as a CCD camera for imaging purposes.

To obtain high transmission efficiency through a capillary by total external reflection, requires constraints on important properties of the capillary. To obtain total external reflection, the incidence angle of the x-ray on the capillary wall must be typically less than about 0.2 degrees, even less for the higher energy x-rays. More specifically the critical angle can be expressed in mrad as 30/E where E is the energy of the x-ray in keV. The local roughness must be controlled to be less than about 1 μm. Waviness in the wall surface must typically be controlled to a level where in a typical scatter the average deviation from a perfect reflection is less than about 0.3 mrad. Such polycapillary fibers have been fabricated successfully and have demonstrated the required transmission efficiency.

These polycapillary optics hold the potential for significantly improved x-ray fluorescence and x-ray diffraction measurements, while potentially improving the overall quality of the data obtained and reducing the mass and power requirements for the instrument. Polycapillary optics also have potential for imaging applications in x-ray

astronomy. Preliminary proposals have been prepared to obtain funding to design and test polycapillary x-ray optics for planetary measurements.

5.0 TECHNICAL TRANSFER

Efforts in technology transfer have been largely focused on a concept, "teleforensics," which envisions the transfer of much of the NASA planetary measurement remote sensing technology, telemetry technology and data compression software developed for space exploration to the development of remote sensing instruments to be used for forensic science. The fundamental concept is to make use of low power, light weight instruments to be used at a crime scene, frequently robotically transported, together with a transmission system that can make use of satellite communication and software developed for data compression to instantly transmit the data obtained to a central location, such as a state forensic laboratory.

The information obtained on site will permit the relatively few forensic experts to deal with multiple crime scenes by having instant communication with personnel on the scene without having to be physically present at any particular site. Robotically controlled instrumentation has the further advantage that evidence can be obtained, for example, at a crime scene such as arson long before sentient beings could enter the scene. This reduces the possibility that evidence is lost through environmental dispersion.

Meetings were participated in at the Goddard Space Flight Center, hosted by the National Institute of Justice and the Goddard Space Flight Center, and at the Connecticut Forensic Laboratory in Meriden, CT, hosted by the head of the laboratory, Dr. Henry Lee. The former meeting introduced law-enforcement personnel from many national and state agencies to the technology available from NASA developed instrumentation, software and systems. The meeting at the latter location was to familiarize NASA and associated personnel with the scientific and legal issues associated with evidence gathering and analysis.

The presentations at these meetings have resulted in a concept for implementing NASA technology in a system that can serve the collective justice agencies. A standard hardware and software system would be installed with a telemetry system that would be common to all instruments. In this way, the development of new instruments can be routinely and inexpensively incorporated into the system through the common telemetry interface. The development of new instrumentation, or the modification of instruments to satisfy the field requirements in law enforcement can be undertaken by research groups in government laboratories or universities. Field testing of the instruments will be undertaken at selected law-enforcement sites, where rigorous constraints of operational conditions and legal requirements can be applied to ensure the viability of any new technique.

From these meetings, all parties thought such a program could provide great value to the law-enforcement community. A memorandum of understanding is being prepared to initiate such a program. If undertaken, this program can provide a significant technology transfer that will have major benefits in prompt and efficient evidence gathering at crime scenes.

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A neutron generator system with a large Ge detector was used to characterize the NEAR Gamma Ray Spectrometer. Also, the Engineering Model Unit for the NEAR mission was evaluated and repaired. Additional activities included investigations of the applicability of polycapillary optics for x-ray detection and technology transfer activities involving NASA technology in forensic science.

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